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MKWS Project

Combustion parameters analysis for a liquid propellant rocket engine Rocketdyne F-1

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1 Introduction

Rocketdyne F-1 was the first rocket engine that guided humans to the moon. It is indisputably one of the best achievements of humanity, therefore the above-mentioned engine is one of the most famous and most powerful motors of all times. The following work will present approached parameters of combustion for the Rocketdyne F-1 rocket engine. In order to complete the calculations Cantera library shall be used. Results will be compared to the experimental data contained in the trainig manual provided by The Rocketdyne Division.

2 Model

Assumptions

- Fuel: kerosene (RP-1)
- Oxidizer: oxygen (O_2)
- Volume of combustion chamber: $0,7m^3$

Due to the lack of suitable kerosene model in the Cantera's resources, it was necessary to use a surrogate fuel model. Substitute model applied to calculations was the Dagaut model developed by Centre Europeen de Recherche et de Formation Avancee en Calcul Scientifique. The surrogate is made up of 74% of $NC_{10}H_{22}$, 15% of PHC_3H_7 and 11% of CYC_9H_{18}. For above substances the following properties have been defined:

Input values used for calculations are shown in the following table:

Input data	Oxidizer	Fuel
State of matter	gas	gas
Pressure [Pa]	$1,2797 \cdot 10^7$	$3 \cdot 10^5$
Temperature [K]	800	300

For analysis four following reservoirs have been used:

- Oxidizer (Oxygen)
- Fuel (Kerosene)
- Igniter (H radicals which ignite mixed flow of fuel and oxidizer)
- Combustor
- Exhaust (N_2 molecules)

Moreover, after computation specific impulse of the rocket has been defined. Equation based on [4]

$$Isp = \sqrt{\frac{k\frac{R}{M_{gas}}T_c}{k-1}\left[1-\left(\frac{p_e}{p_c}\right)^{\frac{k-1}{k}}\right]} \cdot \frac{1}{g}$$

where:
k - ratio of specific heats, $\frac{cp}{cv}$
p_e - nozzle exit pressure
p_c - combustion chamber pressure
T_c - combustion chamber temperature
R - exhaust flow universal gas constant
g - gravitational acceleration

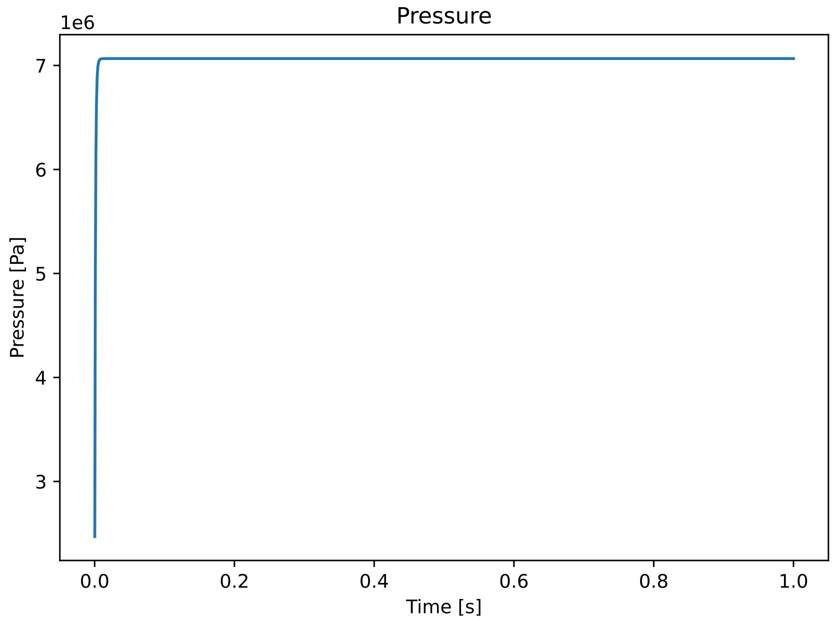
Necessary parameters were taken from [1]

Thrust level (sea level)	1,522,000 pounds
Specific impulse (sea level)	265.3 seconds
Total propellant flowrate	5,736 lb/sec (40,644 gpm)
a. Fuel	1,754 lb/sec (15,606 gpm)
b. Oxidizer	3,982 lb/sec (25,038 gpm)
Mixture ratio	2.27:1
Expansion ratio	16:1
Thrust chamber pressure	1,125 psia
Thrust chamber temperature	5,970° F
Thrust chamber exit pressure (16:1)	9.6 psia
Fuel pump discharge pressure	1,870 psia
Oxidizer pump discharge pressure	1,602 psia
Gas generator flowrate (included in total)	167 lb/sec
a. Fuel	118 lb/sec
b. Oxidizer	49 lb/sec
Gas generator mixture ratio	0.416:1
Gas generator combustor pressure	980 psia
Gas generator temperature	1,453° F
Turbine speed	5,492 rpm
a. Time from turbopump initiation to rated speed	5.2 seconds
b. Time from cutoff to zero rpm	3.5 seconds
Turbine brake horsepower	53,146 hp
Nozzle extension coolant gas temperature	1,138° F
Hydraulic recirculation flowrate	11.6 ±1.1 gpm at 1,500 psig
Engine dry weight (average)	18,619 pounds

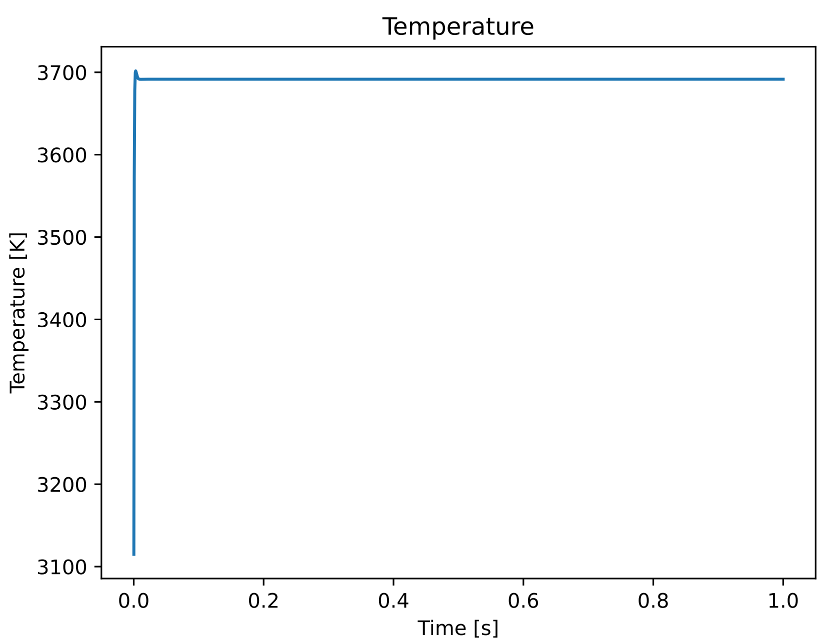
Figure 1-5. Nominal F-1 Engine Parameters

3 Results

3.1 Pressure



3.2 Temperature



3.3 Specific Impulse

$$I_{sp} = 209.3s$$

4 Comparison

	Approached	Experimental	Relative Error [%]
Pressure [Pa]	$7.06 \cdot 10^6$	$7 \cdot 10^6$	0.857
Temperature [K]	3691.6	3572.04	3.35
Specific Impulse [s]	209.3	265.3	21.1

As we can see simulation results are acceptably close to real parameters.

5 Conclusions

In conclusion, Cantera library is sufficient for laminar flow in constant volume simulations. The reason of difference in Specific Impulse might be the usage of substitute model of kerosene, which change the molecular weight of gas. Moreover, to make the simulation closer to reality we used Oxygen as the oxidizer instead of air, which is recommended in the Dagaut's mechanism. That might be another reason for different molecular mass of gases in the chamber.

6 Bibliography

[1] https://www.pdf-archive.com/2016/10/21/rocketdyne-f1-engine-manual/preview/page/10/
[2] https://chemistry.cerfacs.fr/en/chemical-database/mechanisms-list/dagauts-mechanism/
[3] https://github.com/lyczeko/MKWS_kerosene_combustion/blob/master/projekt_MKWS/projekt1_MKWS2018_ALyczek.pdf
[4] https://github.com/KrzysiuPietrzak/MKWS_project/blob/master/Krzysztof_pietrzak_MKWS.pdf//

7 Github

Link to GitHub account:
`https://github.com/roch00/MKWS2022_RockedyneF1`